Simulation of using OSD in a sub-basin of Belo Horizonte City – MG, Brazil

Simulation de l'utilisation d'un bassin de retention dans un sous-bassin dans la ville de Belo Horizonte - MG, Brésil

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RESUME

La ville de Belo Horizonte a souffert de problèmes constants d'inondation durant les dernières saisons de pluie. Une façon d'améliorer le fonctionnement du système de drainage de la ville est d'utiliser des techniques alternatives, comme des réservoirs d'eaux pluviales placés à la source. Afin d'évaluer l'efficacité de cette technique, l'utilisation de réservoirs a été simulée sur un sous-bassin de l'Avenue Francisco Sa, située dans la ville de Belo Horizonte, qui présente des problèmes d'inondation. Le logiciel utilisé est SWMM et les simulations ont été faites avec et sans réservoirs, utilisant deux épisodes de pluie avec un temps de retour de 10 ans : l'une d'une durée de 45 minutes et l'autre de 60 minutes. Dans les situations avec réservoirs, une réduction de 50% du débit de pointe a été observée, par rapport au scénario sans réservoir. Il a également été observé, lors de la simulation avec des précipitations d'une durée de 45 minutes, que le débit de pointe généré par le sous-bassin versant étudié dépassait le débit maximal produit par les précipitations de 60 minutes.

ABSTRACT

The city of Belo Horizonte has been suffering from constant flooding problems in the last rainy periods. One way to improve the drainage sistem functioning of the city is the use of alternatives techniques, as On-site Stormwater Detetion - OSD. To evaluate the efficacy of this technique, it was simulated the use of OSD in lots of sub-basin Av. Francisco Sa Stream, located in Belo Horizonte City, witch has flooding problems. The program used was the Storm Water Mangement Model – SWMM and simulations were made for situations with and without OSD and using two rainfall events with 10 years of return time, one with 45 minutes of duration and other with 60 minutes of duration. In the cases of OSD in the sub-basin, there was a 50% reduction of peak discharge compared to the scenario without OSD. It was also observed that in the simulation with 45 minutes duration rainfall was generated a peak discharge in the sub-basin studied greater than the maximum flow produced with the 60 minutes rainfall.

KEYWORDS

Flooding, Modelling, On-site Stormwater Detetion – OSD, Urban hydrology.

1 INTRODUCTION

In the last rainy seasons, the city of Belo Horizonte suffered with serious flooding problems, caused not only because of high intensity rainfalls, but mainly by the inability of the drainage system to carry the runoff flows.

The urbanization city process happened in the same way of the most biggest brazilian cities, without concernning to maintain or compensate the lost of infiltration due the soil sealing e and not considering the natural drainage of stormwater. Interventions in streams facilitated the inapropriate occupation of its margins, areas that were naturally flooded.

The use of Best Management Practices – BMPs, as On-site Detention Stormwater – OSD, is one way for reducing the flood wave propagations in the drainage systems. These small reservoirs store the excess of stormwater generated in lots and launch small flows in public drainage system, which helps to promote the reduction of flood risk.

The installation of OSD promote citizen participation in the management of urban drainage, forcing them to maintain the flow peak from theirs lots near to the natural flows, reducing the public expenditures with large works.

To assess the impact of the OSDs implementation in the drainage system, it was decided to perform a simulation using the program SWMM (USEPA, 2011) in a sub-basin of Belo Horizonte City which suffering with flood problems. It was compared the peak flows and hydrographs output of two scenarios, one with a sub-basin totaly impermeable and another with the OSDs adoption.

2 METHODS

2.1 Selection of sub-basin

As the goal of the study was to analyze the use of OSDs that promote the improvement of the functioning of the drainage system, the main criteria used to select the sub-basin to be studied in Belo Horizonte was verify if it has flooding problems.

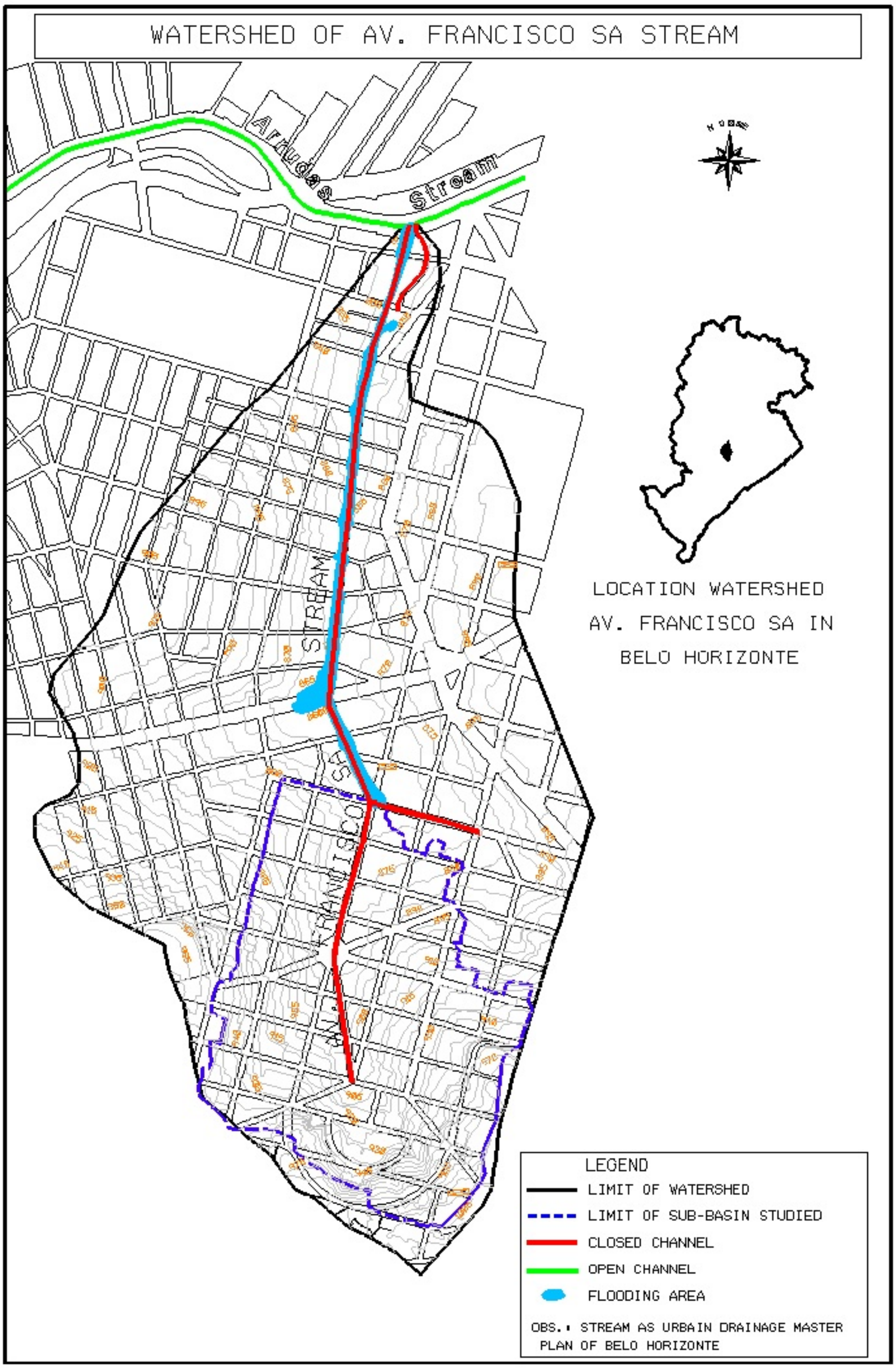
One of the instruments used to choose the sub-basin was the Belo Horizonte Flooding Map (2009), elaborated for municipality. This document mapped the locations potentially susceptible to flooding in each catchment of the city.

It were also assessed the urbanization degree of sub-basin and its location, prioritizing those located at the headwaters to facilitate the hydrologic modeling.

The procedures and instruments used to perform the choice were:

- Analysis of Belo Horizonte Flooding Map (2009) – the catchment of the sub-basin to be studied should necessarily have a flooding area registred in Belo Horizonte Flooding Map;
- Analysis of satellite image – it was evaluated the urbanization degree of sub-basin, prioritizing the one which had a high impermeabilization degree;
- Analysis of sub-basin location – it was verified through hydrograph map of the municipality if the sub-basin to be studied was at the headwaters to facilitate the hydrologic modelling.

After the analyzes, it was decided to study the headwaters sub-basin of Francisco Sa stream, a tributary of the right bank of Arrudas stream. The figure below shows the watershed of Francisco Sa stream with counter lines and the sub-basin studied. In field inspections it was found that the boundary of the sub-basin studied was not that one defined by the Urban Drainage Master Plan of Belo Horizonte.



Map of Av. Francisco Sa Stream watershed and the sub-basin studied

According to the Municipal Sanitation Plan of Belo Horizonte (Municipality of Belo Horizonte, 2010), the watershed of Av. Francisco Sa stream has an area of approximately 216 ha, with a resident population of 26,106 inhabitants in 2010.

The sub-basin chosen to perform the simulations has an area of 59.62 ha and for being located in the south region of the Arrudas stream channel, it soil can be classified as hydrologic group D, according to the classification of Soil Conservation Service method.

The survey of the number and size of lots of sub-basin was done based on the cadastral plant CP-023 001 K, that shows the registration of the parceled lands and have been approved by the Urban Regulatory Secretary of Belo Horizonte.

According to Law 9.959 - Parceled, Land Use and Occupation of the Belo Horizonte City the sub-basin area is classified as ZD - Zone Density, which allows to make impermeable of up to 100% of the ground.

According to the Geographic Information System of Drainage, Belo Horizonte GIS-Drainage, the macro drainage system of the sub-basin consists of a concrete channel of 735 m length, with a cross section of 1.5 m x 1.5 m. Dimensions channel information and the upstream and downstream channel bottom levels were obtained through registration forms of macro drainage structure.

2.2 Modeling fo sub-basin

Once defined the sub-basin that would be studied, it was held simulations of sub-basin drainage system operation for both situations, with and without OSD.

The precipitations used in the simulations were with Return Time of 10 years and with the following durations:

- 45 minutes, that is the critical duration for a OSD deployed in a 360 m² lot;
- 60 minutes, that is the of summing the critical duration to the OSD (45 minutes), plus the time of concentration to the sub-basin studied (15 minutes).

2.2.1 Definition of the lot hydrographs

Rainfall intensity was calculated using the IDF equation of municipality and the temporal distribution of rainfall was obtained by the curves of rainfall temporal distributions for different exceedance and durations probabilities elaborated for the Metropolitan Region of Belo Horizonte, based on the Huff method (1967), by Pinheiro and Naghettini (1998).

The discretizations of hydrographs were performed using intervals of five minutes for the critical duration of OSD and six minutes for the critical situation of the sub-basin.

After surveying the areas of all lots inside the sub-basin, the lot hydrographs were calculated using the Soil Conservation Service method, adopting the value of 5 minutes fo the time of concentration in the situation when soil is completely impermeable (Municipality of Belo Horizonte, 199 -) and 10 minutes when the soil is under natural conditions (Municipality of Belo Horizonte, 2004).

It was adopted the Curve Number - CN of equal to 98 for the lots with soil completely impermeable and the CN equal to 84 for the soil in the natural conditions, as recommended by the Urban Drainage Master Plan of Belo Horizonte (2000).

2.2.2 OSD Dimensioning

The OSD volume for each lot was calculated by multiplying the lot area and the rate of 29 liters / m², defined by Drumond (2012). This is the volume necessary for storage in relation to impermeable area for lots inserted into soil hydrology group D in Belo Horizonte.

The diameters of the discharge pipes of the OSDs was defined using the general equation for orifices:

$$Q = Cd.A.\sqrt{2gh}$$

which:

Q = flow rate (m³/s);

Cd =discharge coefficient;

A = cross-sectional area of the pipe (m²);

H = height of water over the tube axis (m).

The peak flow considered in the formula was calculated for the situation with the natural soil, the discharge coefficient used was 0.90, as found in laboratory study by Drummond (2012) and the useful height defined for OSD was 1.00 m.

The diameter of the discharge tube ranged from 25 to 100 mm, being defined according to the peak flows of the lot hydrographs in natural soil conditions.

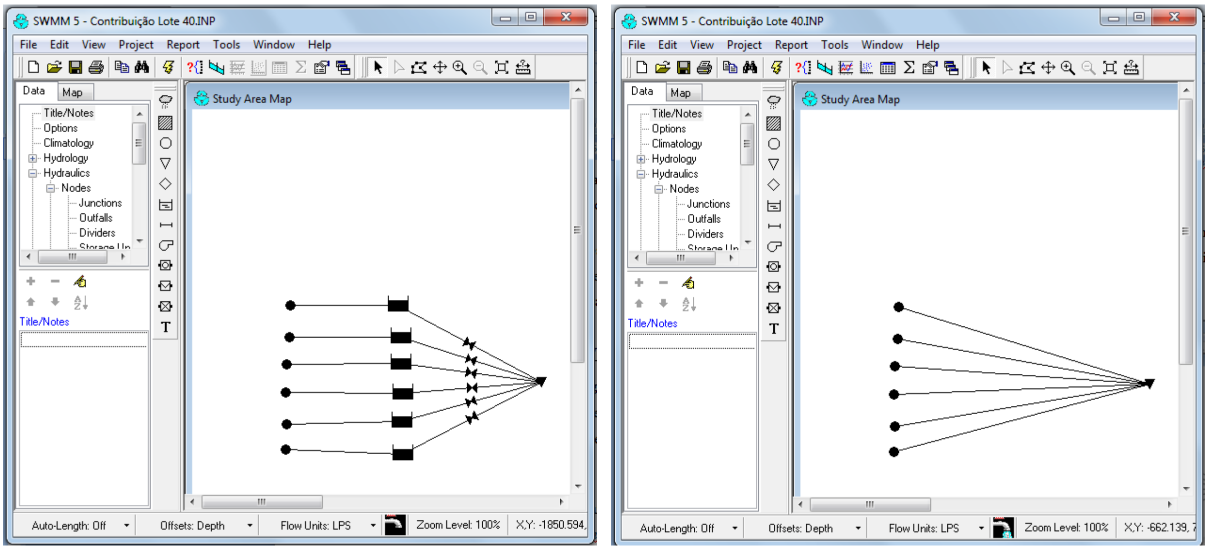
2.2.3 Simulation sub-basin in SWMM

Once calculated the hydrographs, volumes and diameters of discharge tubes of OSDs of each lot, it were determined the contribution of blocks for each side of the street, considering that each lot discharges its waters into the street, in front of it.

The contribution of each face of the blocks was calculated using the program SWMM – Storm Water Management Models. The lots were represented by junctions, a tool that allowed to insert directly the output hydrographs of lots.

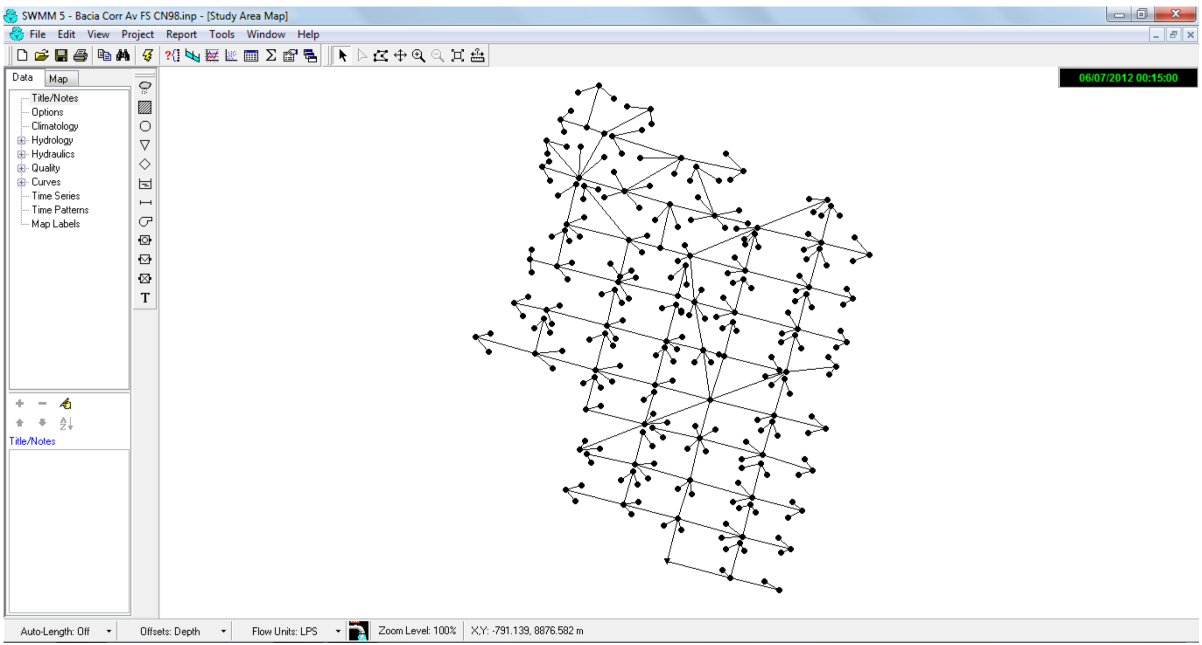
For the two simulated rainfall were calculated two hydrographs for each face of the blocks, one produced with OSDs inserted in lots and another without OSDs. In the simulation with OSDs, it was inserted a conduit of one meter length connecting the junction with storage unit. At the output of storage unit was inserted the tool « orifice » which restricted the outflow and connected the storage unit to the outfall, where it was possible to obtain the hydrograph output in the face of a block. The settings of the simulations can be seen in Figures below. In the simulation without OSD, it was connected the junction directly to the outfall.

(a) (b)



Settings simulations of contribuitions of the sides of blocks (a) Lots with OSD (b) Lots without OSD

After determinating of the contributions on each side of every block of the sub-basin, it was set up the contribution across the sub-basin studied, as shown in Figure below. In this simulation, the contributions of the faces of the blocks were represented by junctions and their linkages were made by conduits.



Setting of contribuitions in sub-basin Av. Francisco Sa Stream

As described before, the dimensions of the macro-drainage strucutres were inserted using the registration forms obtained from the Geographic Information Drainage System of Belo Horizonte. In sections where it was not obtained informations about the existence of drainage networks it was considered one meter diameter pipes with slope equal to existing streets.

The area of contribution from the streets was determined by multiplying its length by an average width of 15 meters. After defining this area, it was calculated the contribution of hydrograph in the same way for lots with impermeable soil. The hydrographs were inserted into junctions located at the beginning of each street.

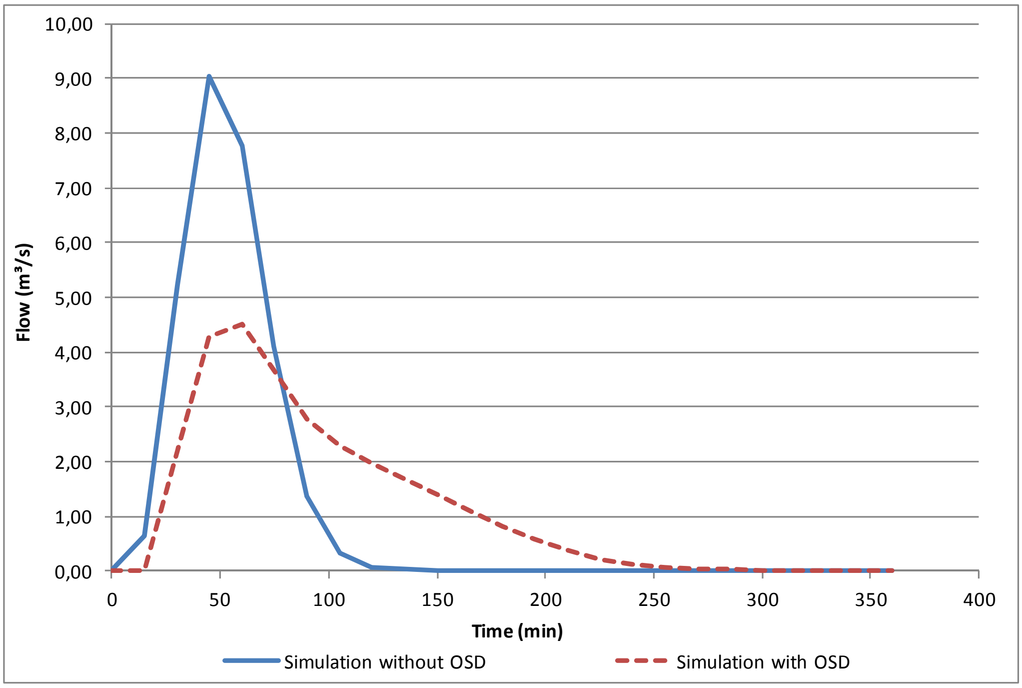
After insertion of all hydrographs, the simulation was performed and it was obtained the hydrograph output in the sub-basin.

3 RESULTS AND DISCUSSION

Below are shown the results of the simulations for the two studied rainfalls, with return time of 10 years.

3.1 Simulation to the rainfall with 10 years of Return Time and Duration of 45 minutes

The simulation results with the rain 45 minutes duration carried out in the sub-basin of Francisco Sa stream showed a 50% reduction in peak flow for the output hydrographs calculated with OSDs compared to those and without OSDs, as can be seen in Figure below.



Hydrographs generated in simulations of the sub-basin Av. Francisco Sa Stream

The hydrograph generated in lots without OSDs had a peak flow of 9.00 m³/s with a time base of approximately 2 hours, whereas in hydrograph generated in simulation with the OSDs it was obtained a peak flow of 4.50 m³/s and a time base of approximately 4 hours.

None strech of the main channel there was insufficient flow capacity. In the final stretch of the main channel, the maximum the water depth was 63 cm and happened at 45 minutes after the start of the simulation without OSD.

The results showed that up to three hours simulation, the flow regime in this stretch was supercritical since the Froude number was always higher than 1.0 (one) during that period. The highest value obtained for the Froude number was 2.94 and occurred at one hour and fifteen minutes of simulation. The results of the flow rates, velocities, the water depth and the Froude number in the last stretch of the main channel during the simulation are shown in Table below.

Results in the final stretch of the channel in the simulations without OSD

Time (H:M)	Flow (m³/s)	Depth (m)	Velocity (m/s)	Froude Number
0:15	0,61	0,11	2,77	2,66
0:30	5,09	0,43	5,92	2,88
0:45	8,80	0,63	7,03	2,84
1:00	7,57	0,56	6,74	2,87
1:15	4,00	0,36	5,53	2,94
1:30	1,32	0,17	3,80	2,90
1:45	0,33	0,07	2,28	2,70
2:00	0,07	0,03	1,27	2,39
2:15	0,02	0,01	0,82	2,16
2:30	0,01	0,01	0,62	2,01
2:45	0,01	0,01	0,50	1,92
3:00	0,00	0,01	0,42	1,84

In the simulation of the sub-basin with the OSDs, the maximum water level in the final stretch of the main channel was 39 cm and occurred one hour after the start of the simulation.

According to the results calculated by SWMM program, the flow regime in the final stretch of the canal was critical in the first 15 minutes of simulation and turned into supercritical until the end of the simulation. The results of the main hydraulic parameters of this stretch are shown in the Table below.

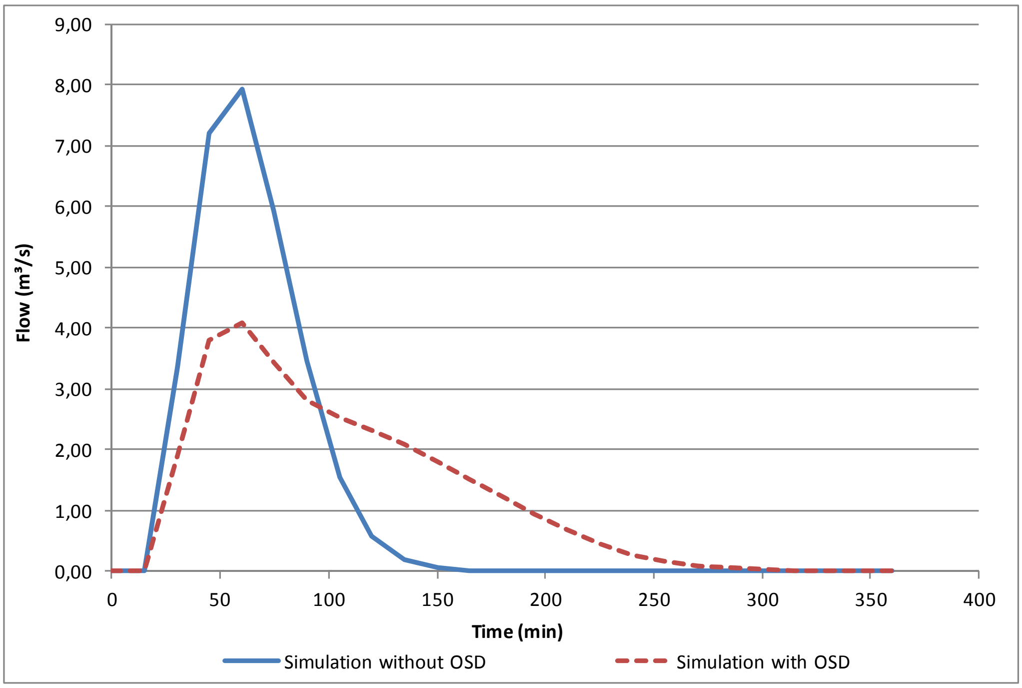
Results in the final stretch of the channel in the simulations with OSD

Time (H:M)	Flow (m³/s)	Depth (m)	Velocity (m/s)	Froude Number
0:15	0,01	0,01	0,35	1,00
0:30	2,14	0,24	4,42	2,87
0:45	4,15	0,37	5,57	2,91
1:00	4,37	0,39	5,67	2,92
1:15	3,56	0,34	5,31	2,93
1:30	2,70	0,28	4,84	2,92
1:45	2,24	0,25	4,53	2,91
2:00	1,93	0,22	4,30	2,90
2:15	1,65	0,20	4,07	2,88
2:30	1,37	0,18	3,81	2,86
2:45	1,09	0,16	3,50	2,84
3:00	0,81	0,13	3,15	2,80
3:15	0,56	0,10	2,75	2,74
3:30	0,36	0,08	2,33	2,66
3:45	0,22	0,06	1,91	2,57
4:00	0,12	0,04	1,54	2,46
4:15	0,07	0,03	1,24	2,34
4:30	0,04	0,02	1,01	2,24
4:45	0,03	0,02	0,85	2,14
5:00	0,02	0,01	0,72	2,07

In the simulation with OSDs, the results showed that did not occur increasing on peak flows with the simultaneous arrival of delayed hydrographs, indicating that the use of this compensatory technique may be able to reduce the impact foram the impermeable soil.

3.2 Simulation to the rainfall with 10 years of Return Time and Duration of 60 minutes

In simulations for rainfall with duration equal to the sum of the concentration time of the watershed and the critical duration of OSD, the results showed a reduction of peak discharge equal to 50%. Without installing the OSDs, the maximum flow output in the sub-basin studied was 9.04 m³/s and in the simulation with control devices it was 4.49 m³/s, as can be seen in Figure below.



Hydrographs generated in simulations of the sub-basin Av. Francisco Sa Stream

It can be observed that the efficacies of using OSDs in reducing the peak discharges in the simulations with the precipitation of duration of 45 and 60 minutes were similar. However, the precipitation with duration of 45 minutes produced a peak discharge greater than one for rain duration of 60 minutes.

In the simulation with sub-basin without OSDs for precipitation with duration of 60 minutes, there was no flooding in stretch of the main channel. In the final stretch, the maximum water depth was 57 cm, occurring at 60 minutes after the start of the simulation without OSD.

The results showed that in this stretch of the canal, the flow regime worked as supercritical in the first three hours of the simulations, except for the first 15 minutes. At one hour and thirty minutes of the simulation was obtained the largest number of Froude, 2.93. The simulation results of this stretch are shown in the Table below.

Results in the final stretch of the channel in the simulations without OSD

Time (H:M)	Flow (m^3/s)	Depth (m)	Velocity (m/s)	Froude Number
0:15	0,01	0,01	0,33	0,95
0:30	3,25	0,32	5,11	2,89
0:45	7,00	0,53	6,56	2,87
1:00	7,72	0,57	6,77	2,86
1:15	5,79	0,47	6,21	2,91
1:30	3,37	0,32	5,22	2,93
1:45	1,52	0,19	3,97	2,90
2:00	0,56	0,10	2,77	2,77
2:15	0,19	0,05	1,84	2,57
2:30	0,06	0,03	1,19	2,35
2:45	0,02	0,01	0,77	2,14
3:00	0,01	0,01	0,58	1,99

In the simulation of the sub-basin with OSDs, the maximum water level in the final stretch of the main channel was 36 cm, 3 cm less than in the simulation with the rain 45 minutes.

In the simulation with OSDs, the flow regime in the final stretch of the canal was supercritical. The results of the main hydraulic parameters of this stretch are shown in the Table below.

Results in the final stretch of the channel in the simulations with OSD

Time (H:M)	Flow (m³/s)	Depth (m)	Velocity (m/s)	Froude Number
0:15	0,01	0,01	0,35	1,02
0:30	1,84	0,22	4,19	2,85
0:45	3,69	0,34	5,35	2,91
1:00	3,96	0,36	5,49	2,92
1:15	3,35	0,32	5,20	2,92
1:30	2,73	0,28	4,85	2,92
1:45	2,47	0,26	4,68	2,91
2:00	2,27	0,25	4,55	2,91
2:15	2,03	0,23	4,37	2,90
2:30	1,76	0,21	4,16	2,89
2:45	1,48	0,19	3,92	2,87
3:00	1,20	0,17	3,63	2,85
3:15	0,92	0,14	3,30	2,81
3:30	0,67	0,11	2,92	2,77
3:45	0,45	0,09	2,52	2,7
4:00	0,28	0,07	2,10	2,61
4:15	0,16	0,05	1,68	2,50
4:30	0,09	0,03	1,36	2,39
4:45	0,05	0,02	1,11	2,28
5:00	0,03	0,02	0,92	2,19

The simulations showed that precipitation with duration of 45 minutes produces a higher peak discharge, being more critical to sub-basin of Francisco Sa stream. The deployment of OSDs reduced by up to 50% of peak flow generated with soil impermeabilization for the two studied rainfall, contributing to the better functioning of the drainage system and to reduce flood problems.

4 CONCLUSION

In the end of this work, it was verified that OSDs are effective in offsetting the impact on urban drainage system with impermeable soil and infiltration capacity reduction.

The simulations with the OSDs in lots of the sub-basin Francisco Sa stream, for the rains with duration of 45 and 60 minutes, showed that its use may reduce 50% the peak flows compared to the lot situation totally impermeable without control device. It is important to note that, to obtain the intended attenuatioin of the hydrographs, the discharge structure and the volume of the OSD must be appropriately dimensioned.

The simulations showed that the control devices at the source can help to reduce the problems of flooding in urban watersheds.

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